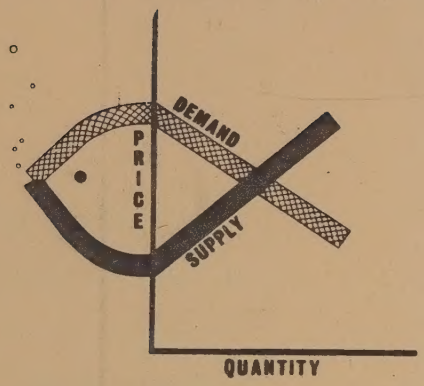

Bio-Economic Model of a Fishery

by

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DIVISION OF ECONOMIC RESEARCH

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(continued on inside back cover)

Fish is the only major commodity exploited by man where he retains the ancient role of the hunter. In everything else man has long ceased to rely upon the vagaries of nature and has assumed control over the production process. This is the special nature of a fishery; man, so to speak, accepting what nature chooses to give and having very little, if any, ability to influence it except in a negative fashion. From the time of Marshall to Gordon (1954) economists ignored the problem. Gordon's seminal article contained many insights into the interplay between biology and economics, but it also unfortunately triggered many sterile debates because of his peculiar formulation of the problem.

The following model is deterministic and static, which is bad considering that a fishery is anything but deterministic and static, but it is a place to begin. In the end, a deterministic model must be replaced by a stochastic model, especially if a rational fishery management policy is to be imposed upon the community. Let us say that the conception of goals for which fishery management must work will come from a clear understanding of a deterministic model, but implementation will have to take place within a stochastic model.

Simplified Fishery Population Dynamics

The range of most species of fish is narrowly circumscribed by one or more of the following environmental factors: temperature, salinity, depth, bottom conditions, and food supplies. These, in various combinations along with natural predators, limit the growth of a fish population to a finite level and the area in which it lives. The ecological system within which the fish live is extremely complex, and a minor change in any part of the system may cause anything from explosive growth of a part of the system to extinction of a species.

To simplify outling the model we must assume that the environmental factors remain constant. The growth of the useful weight of a fish population in a particular fishery is usually assumed to follow an S-shaped curve. The population increases (1) slowly at lower levels, limited by reproductive capabilities of small numbers and the small numbers of fish that are growing, (2) rapidly in the intermediate range, as larger numbers of fish produce more eggs than can survive, and growth is not limited by pressure on food supplies, (3) slowly at higher levels where pressure on food supplies impedes the population growth in a manner akin to Malthus' "iron law of wages" where weight loss due to deaths in the population will just offset births and weight gains by the survivors.

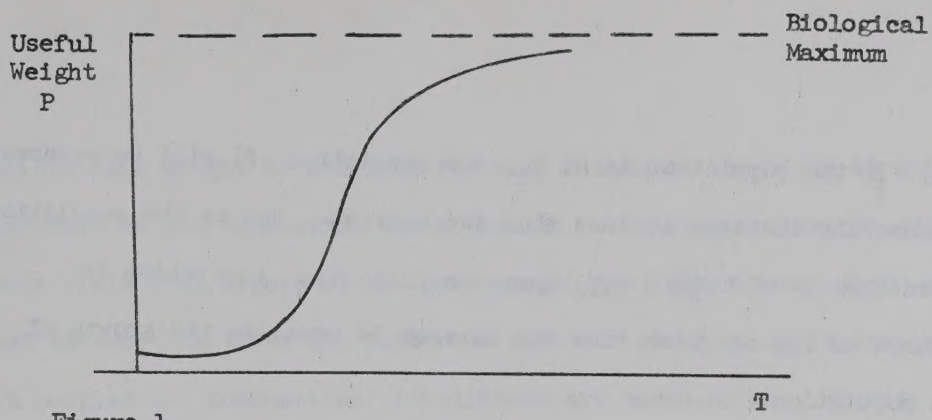

Figure 1

Assuming the environmental parameters constant, we can say that the population growth is a single valued function of the population or

$$\frac{dp}{dt} = F(P) \qquad (1)$$

The function (1) is usually assumed to have the shape shown in figure (2):

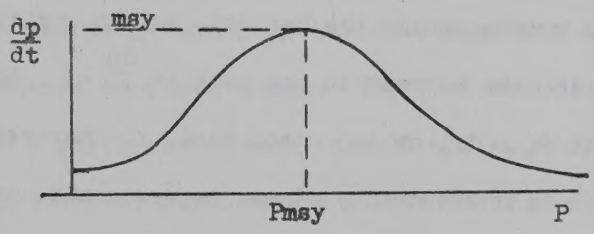

Figure 2

This shape is preferred because with it the population always tends toward stability in the following way:

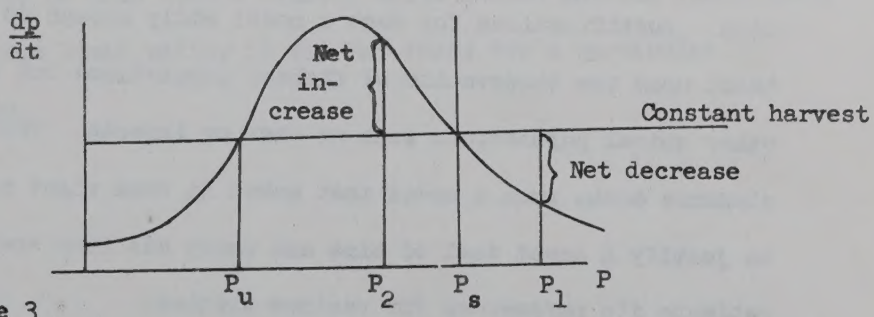

Figure 3

Here we show the effect of a constant harvest per unit of time upon the fish population. (fig. 3).

1(a) If the population is at P_1, the population (P) will be reduced because the increase is less than the harvest. But as the population is reduced growth ($\frac{dp}{dt}$) will increase until the population is reduced to P_s, at which time the harvest is equal to the growth of the population.

(b) If the population is at P_2 the rate of increase is more than the harvest, so the population will go to P_s again.

(c) Hence P_s is a stable equilibrium.

(2) If the population is at P_u the population will also be in equilibrium as the growth equals the harvest, but an unstable equilibrium. If, for example, the harvest in one year is $\frac{dp}{dt} - \epsilon$, the population will expand to P_s. If, on the other hand, the harvest equals $\frac{dp}{dt} + \epsilon$, the population will eventually fished to (economic) extinction.

The model of population growth is seen to be completely deterministic. Once the process is set in motion it grinds on to its logical conclusion. Justifications for such a model oddly enough do not seem to be based upon the observation of fishery populations but rather upon the other animal populations such as deer or insects. There is a certain elegance about such a model that makes it seem right and unnecessary to justify. A great deal of time and money has been spent in trying to estimate its parameters for various species.

Biologists have sought to estimate for many fisheries the catch at which the increase in the population was a maximum, calling it maximum sustainable yield (MSY, figure 2) and have sought the authority to limit catches by that amount. In those few fisheries that are managed, decisions that affect peoples and communities' livelihoods are based on it. Whether or not a fish population's growth can be usefully approximated by such a function is of course an empirical question.

The Conservation Decision

The central theme in most of the economic literature concerning fisheries is a strong bias toward conservation. Except for a minor qualification by Scott (1953), no one to my knowledge has even suggested that there might be any alternative to conservation. The term usually means that the annual catch in a particular fishery should always be less than the maximum increase in the fish population's weight (MSY) so that the fishery could go on producing fish forever. This is, of course, a value judgment and as such the assumptions behind it should be stated explicitly because it might not always be true that a society would choose maximum sustainable yield as the optimum limit policy if all the facts for a particular fishery were known.

Referring to figure 2, it can be seen that to only capture the MSY in a particular fishery means that a population level P_{MSY} has to be maintained. The ratio MSY/P_{MSY} indicates the rate of return that a society receives by maintaining the basic stock. This ratio, depending upon the species, can vary almost anywhere from zero to infinity. There is some ratio in this range below which society should determine a species should be treated as a mineral deposit, i.e., simply fished until it is no longer profitable and above which conservation should be followed.

I would argue that the critical ratio should be quite high, say in the neighborhood of 20 percent. My reasons are as follows:

1. Todays society is poorer than it will be in the future. Therefore to ask the present to sacrifice for the future by not consuming something that has a low return is inequitable.

2. Fish species are extremely vulnerable to environmental changes, so that a species that is being conserved might all be killed and societies sacrifice may have been for nothing.

3. Some species are very mobile so that a conserved species might just move out of the range of gear being used.

4. Societies tastes might change and a future generation might not appreciate the conserved species so that the sacrifices of the present generation might have been for nothing.

5. Necessary biological parameters without which management decisions cannot be made is in most fisheries too rudimentary so that the evidence should be heavily discounted.

6. Future generations might develop the farming of fish to the point where the present primitive methods of food gathering no longer have to be relied upon.

The above arguments are meant to put the problem in focus so as to eliminate a reflex response to the cry for management and conservation.

Production

Labor and capital, societies imputs in the production of fish, are of course, no different here than in any other industry. For the sake of manageability it will be assumed that as fishery expands, supplies of capital and labor are available to it at constant prices. The arguments presented do not depend upon this assumption.

The relevant productive unit in a fishery is the vessel which transports the fishing gear and fishermen to the fishing grounds and is the prime determinant of catching power.

Studies done for the Bureau of Commercial Fisheries indicate that the long run average cost curve for fishing vessels have the familiar U shape, with economics and diseconomies for a single unit. This is illustrated in Figure 4 where the long run average cost (LRAC) is the locus of minimum average costs for different size vessels.

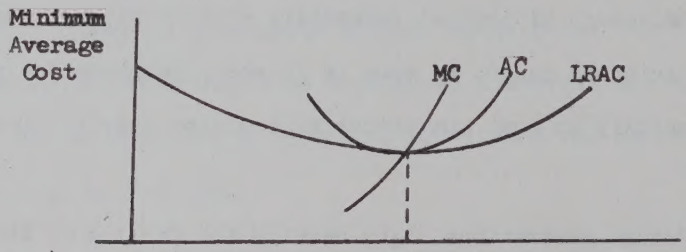

Figure 4

In the typical industry although there might be economies of diseconomies of plant size these are not thought to be important as long as the least cost plant only contributes a small part of the industry output. As new plants are built they are just built at the optimum size. Figures 5 and 6 show the usual expansion paths where for all practical purposes output is expansible indefinitely, assuming factor prices constant, with no change in average costs.

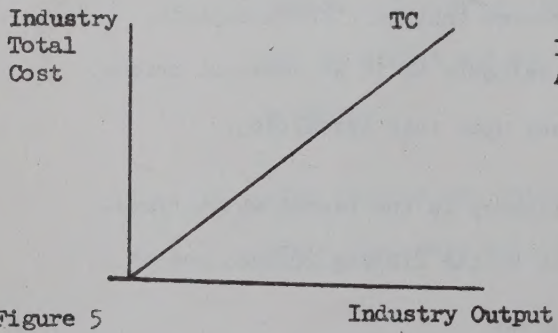

Figure 5

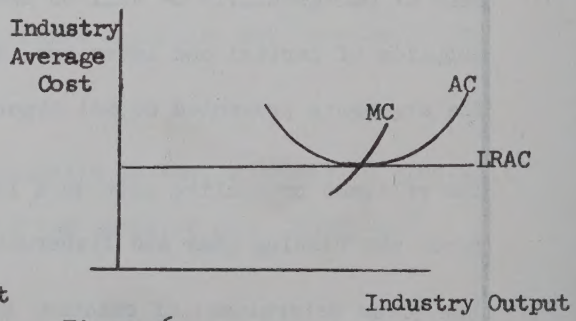

Figure 6

This is not so for a fishery even with a constant fish population because of the way fishing is done. Consider the following model.

Assume that:

1. The fishery is a well defined location and species.
2. The fish redistribute themselves randomly within the fishery after each pass of the nets.
3. That all vessels are identical and have optimum designs.
4. All vessels have the same catching power and costs and that a single vessel can catch K percent of the available population (P) in one year.

If one vessel can catch K percent of P can two vessels catch 2 K percent of P? "Obviously, no!" Part of the fish that the second vessel would have been caught by the first vessel. The first vessel catches K percent of the stock, the second vessel can only add K percent of the remaining fish.

For one vessel where L is total landings

$$L = KP \tag{2}$$

For two vessels

$$L = KP + K\,(P-KP) \tag{3}$$

For N vessels

$$L = (1 - (1-K)^{n})\,P \tag{4}$$

Working with equation (4), average landings (AL) is:

$$AL = \frac{L}{n} = \left(\frac{1-(1-K)^n}{n}\right) P \qquad (5)$$

Differentiating equation (4) with respect to the number of boats we have:

$$M = \frac{dL}{dn} = -(1-k)^n \left[\log_e (1-K)\right] P \qquad (6)$$

Since (1-K) is less than one its natural log is negative and $(1-K)^n$ gets smaller as it is raised to higher powers. This means that the marginal catch is always positive. On differentiating again, equation (7)

$$\frac{dM}{dn} = \frac{d^2L}{dn^2} = -(1-K)^n \left[\log_e (1-K)\right]^2 P \qquad (7)$$

We see that marginal landings are declining throughout all n. Since average landings is the sum of all marginal landings divided by the number of boats, average landings must always be higher than marginal landings for a given number of boats.

Since we assume all vessels have the same costs then as average landings decline as more boats enter the fishery average cost of a pound of fish must increase. In a competitive market boats will enter until price equals average cost.

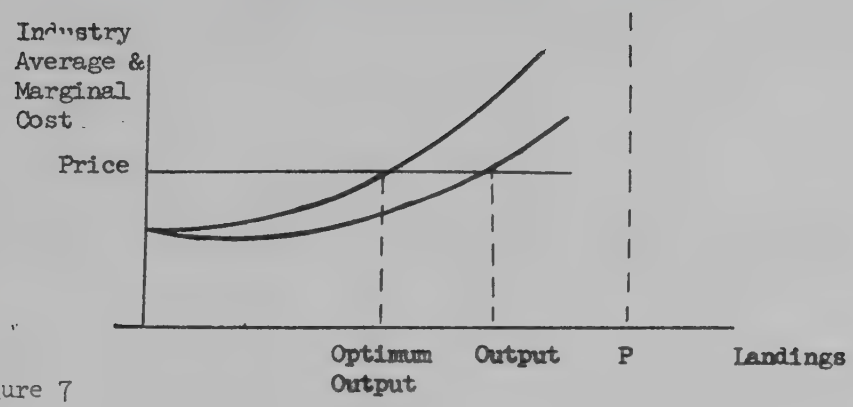

Figure 7

Total landings will approach P asymtotically as the number of boats increase. The interesting feature of this model is that since the extra landings received by adding the nth boat to the fishery is less than average landings, the nth boat is producing fish at a social loss. That is, society is willing to pay less for the nth boats fish than it cost to produce them. Clearly society, after making the usual qualifications about income distribution, would be better off if production was cut back to where marginal cost equals price and resources were released to other pursuits.

The model as it stands is useful for understanding fisheries where the population is produced annually or where the decision has been made that a particular specie should not be conserved.

In a fishery where the species is produced annually P is a random variable that over the relevant range doesn't depend upon the number of survivors from the previous year. In each fishing year a population is produced whose size depends upon varying ecological factors.

Entry would continue until price equalled average cost, and production is at a social loss although private costs are covered.

In a fishery where the decision was made not to conserve it because of the slow growth of the population (P) would move to the left over time by the difference between catch and growth. As P declined average cost would increase and the fishery would contact until boats no longer put to sea to catch the particular species. This is what happened to the Atlantic halibut which was once a large fishery in New England, as time went on yields declined, prices went up but not enough to compensate declining yields and gradually the fishery ceased to exist.

Production and equilibrium when the population should be conserved.

The comparative statics when the fish population should be preserved are unfortunately quite complex. Equilibrium means that the relevant variables are not changing for fishery production this means fish population, catch, boats, technology; and demand.

Let us postulate that an exploited fish population has a growth curve of the following form:

$$P = e^{\alpha - \beta/T} \qquad (8)$$

α and β are parameters and T equals time.

where the size of the exploited population depends upon the mean value of T in a given year. Its derivitive ( ) is

$$\frac{dP}{dT} = e^{\alpha - \beta/T}\left(\frac{\beta}{T^2}\right) \tag{9}$$

and it has the path postulated for fishery growth. (fig. 7)

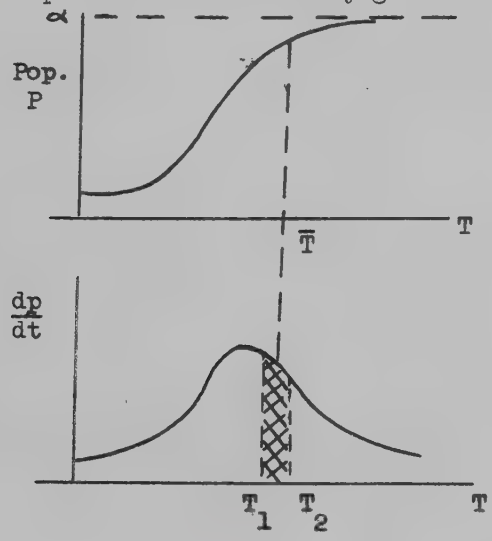

Figure 7

Landings using equation(4) is,

$$L = \left[1 - (1-K)^n\right] P \tag{4}$$

substituting equation (8) for P, landings equation (10) becomes

$$L = \left[1 - (1-K)^n\right] e^{\alpha - \beta/T} \tag{10}$$

The system is in equilibrium whenever landings equal growth

$$L = \left(1 - (1-K)^n\right) e^{\alpha - \beta/T} \approx e^{\alpha - \beta/T}\left(\frac{\beta}{T^2}\right)(T_2 - T_1) \tag{11}$$

The shaded area in figure 7 indicates the growth between time T_2 and T_1 when the population is at $(T_2 + T_1)/2$. Assuming values for the parameters K, α, β, and $(T_2 - T_1)$ we can observe changes in the equilibrium output of the fishery as additional vessels are added to it. The results are summarized in table 1.

The table is divided into two sections. Columns 7, 8, and 9 show the immediate effect of adding a new vessel to a fishery that is in equilibrium with the number of vessels shown in column 1. Column 2 shows the "catching power" of n vessels with the assumed value of K. Column 3 shown the equilibrium standing stock of fish with the assumed parameters for different values of n. Column 4 is the equilibrium catch, or columns 2 times 3. Column 5 shows the extra fish caught by the nth vessel in equilibrium. Column 6 is the average catch at equilibrium for each vessel.

The mechanics work thus. With the assumed parameters the fishery has a standing stock of 2.72 when it is not being exploited. A single boat entering the fishery will initially capture .136 fish (catching power of one boat times the standing stock). Since the population cannot be sustained at 2.72 with this catch the population will be reduced to 1.22 with an equilibrium catch of .06. If a second boat is added at this equilibrium point its immediate impact will be to increase landings to .12,(.10 x 1.22). This gives a short run average

Table 1 . Long run and short run catches for various numbers of vessels.

(1)	(2)	(3)	(4)	(5)	(6)	Changes when one vessel is added at equilibrium points. (7)	(8)	(9)
Number of vessels	Fishing power n vessels $1-(1-k)^n$	Equilibrium standing stock	Long run total catch	Long run marginal catch	Long run average catch	Short run total catch	Short run marginal catch	Short run average catch
0		2.72				.136	.136	.136
1	.05	1.22	.060	.060	.060	.120	.056	.068
2	.10	.87	.087	.027	.043	.120	.038	.040
3	.14	.72	.100	.013	.033	.140	.030	.035
4	.19	.58	.110	.010	.027	.130	.023	.026
5	.23	.50	.115	.005	.023	.130	.019	.022
6	.26	.44	.116	.001	.019	.130	.016	.018
7	.30	.39	.117	.001	.017	.130	.013	.016
8	.34	.34	.116	0	.014	.130	.011	.015
9	.37	.31	.115	-.001	.013	.120	.009	.013
10	.40	.29	.116	0	.012	.120	.008	.012

$K = .05, \alpha = 1, \beta = 1.26, T_2 - T_1 = .1$

catch of .06 and a short run marginal catch of .056. The long run marginal total catch for two vessels will be .087 and long run marginal increase of .027. The long run average catch has declined to .043 from .06. In other words the entry of the second boat has caused the first boats landing to decline by .017. The short run impact of the additional boat was very small but the long run impact large. If the second boats entry was based upon the long run expectation of its short run landings and prices remained constant then both boats will suffer losses in the long run.

The long run increments to the catch become smaller as more vessels are added until finally they actually become negative. This is shown in column 5 and figure 8.

Long and Short Run Costs

Translation of table 1 into cost/unit of fish landed can be done if it is assumed that each of the boats have the same capital and operating costs. The results of this are shown in table 2. It is read in the same manner as table 1. Columns (6) and (7) show the short run cost of an additional unit of fish when the population is the equilibrium i.e., by adding another boat at each level.

Starting at row zero, the cost of a unit of fish at the beginning of a fishery is .74 but the reduction in population will eventually

ble 2. Long run and short run costs.

(1)	(2)	(3)	(4)	(5)	Effect of adding one vessel at equilibrium (6)	(7)
umber of essels	Long run total catch	Long run total cost	Long run average cost	Long run marginal cost	Short run average cost	Short run marginal cost
0					.735	.735
1	.060	.1	1.67	1.67	1.47	1.79
2	.087	.2	2.32	3.70	2.50	2.63
3	.100	.3	3.03	7.69	2.85	3.33
4	.110	.4	3.70	10.00	3.84	4.35
5	.115	.5	4.34	20.00	4.54	5.26
6	.116	.6	5.26	100.00	5.55	6.25
7	.117	.7	5.88	100.00	6.25	7.69
8	.116	.8	7.14	∞	6.67	9.09
9	.115	.9	7.69	∞	7.69	11.11
10	.116	1.0	8.33	∞	8.33	12.25

Assuming cost of one boat and crew is .1

bring this to a cost of 1.67. An extra vessel at level (1) will bring in extra fish at a marginal cost of 1.79 or an average cost of 1.67. Initially a second vessel has little impact on the first vessels cost but as the equilibrium is approached the average cost of each rises to 2.32. The long run marginal cost of the second vessels contribution to total catch is 3.70. As extra vessels are added costs per unit of fish rise until finally the addition of an extra vessel reduces the total catch at which time the cost of an extra fish is infinity. This gives long run cost curves that rising as shown in figure 8.

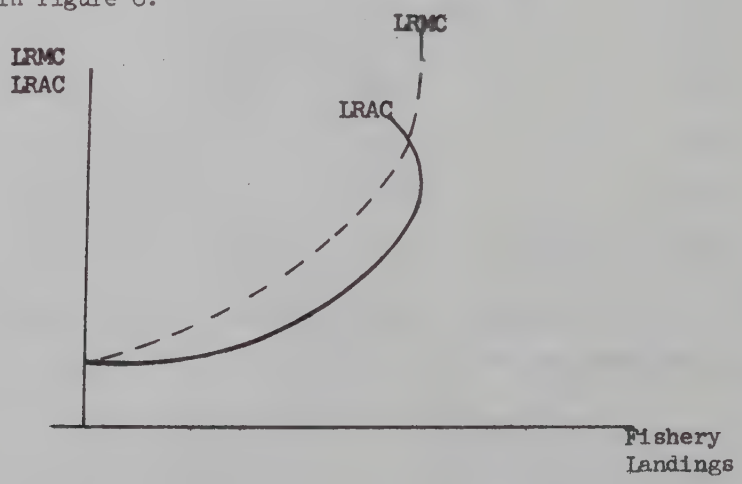

Figure 8.

There is some point at which the addition of extra resources is socially unwarranted because the cost of long run marginal landings

is so high. The individual fisherman does not base his decision to enter upon the social consequences of his action but upon the private costs of doing so represented by the long run average cost curve.

The Demand Functions

The analysis of demand for fish is no different than for any other product. Each species has its own demand function determined in the usual fashion. There may be many fisheries for a single species so that the demand for fish from a single fishery may be quite inelastic. At the other extreme there may be a single fishery for some species with a unique demand curve. These questions are largely empirical but a useful model should be capable of handling all of them.

Product and Demand

The final step is of course the integration of supply and demand. This is done in figure 9.

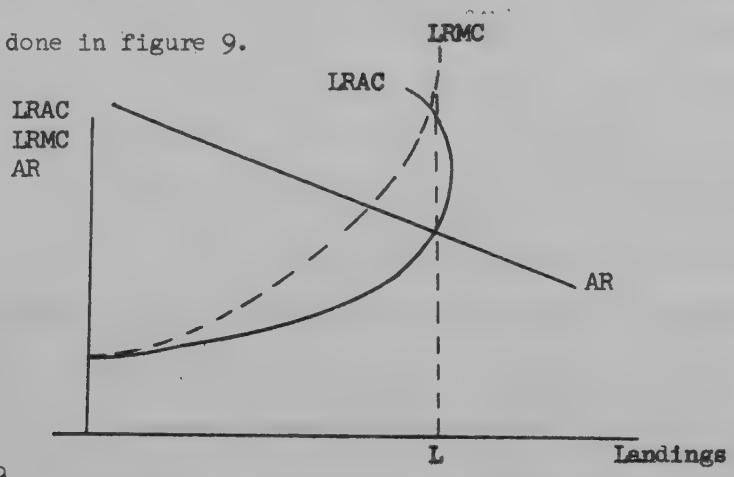

Figure 9.

The fishery will be exploited up to the point where long run average cost (LRAC) is equal to average revenue (AR). This is the point where all private costs are covered and each vessel is making a normal rate of return. The problem is of course that the fish are being produced at a social loss. The cost of bringing an additional unit of fish to the market at this level is in excess of what consumers are willing to pay for it. We have then a industry where the competitive solution is always suboptional. There is no way that an unmanaged fishery can become optimal from the standpoint of resource allocation within the general economy.

Comparison with Prior Work

The model most commonly used in fishery economics was originally formulated by Gordon (1954) and later elaborated on by Scott, Crutchfield, Zellner and others. The model begins with a function that shows the long run relationship between landings and effort (which I have chosen to call vessels) from the exploited fish population. To transform this into an economic model, they assume price of the fish is constant assuming the fish from a particular fishery are only a small part of supplies. They arrive at total revenue curve by multiplying landings by the assumed price.

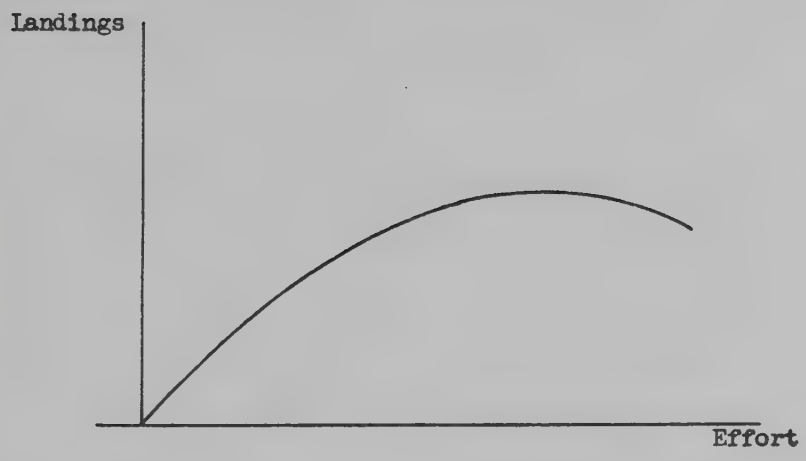

Figure 10.

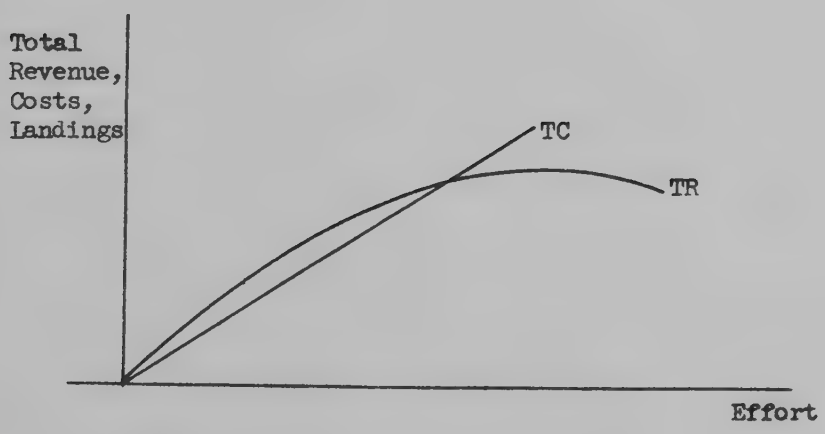

Figure 11.

To arrive at a cost function they assume that total cost is a linear function of effort. The equilibrium condition is that total cost should equal total revenue. The social optimum for production as originally stated by Gordon (1954) was that the fishery should produce a maximum net economic yield or maximize the difference between total cost and total revenue.

A good critique of this model was supplied by Hutchings (1967). One major fault is that it violates the basic rules of economic model building. Demand and supply are both intertwined in the total revenue function, so in a discussion of demand shifts one has to be always cognizant that the landings scale has to change.

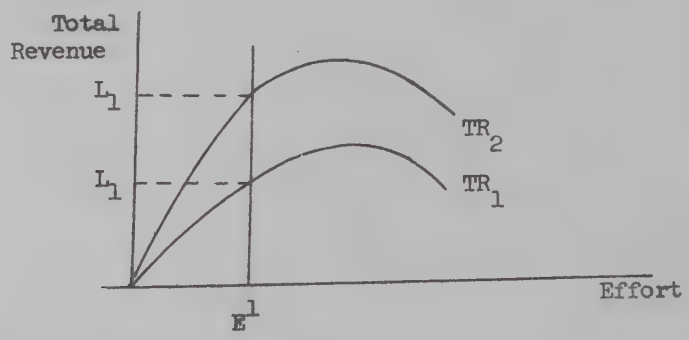

Figure 12.

Referring to figure 12, if price increases, total revenue at E' will increase from TR_1 to TR_2 , but landings will remain the same.

Another problem is the power to handle a general demand function. The model breaks down completely. If price does change with the landings we have, the situation shown in figure 13 where total revenue.

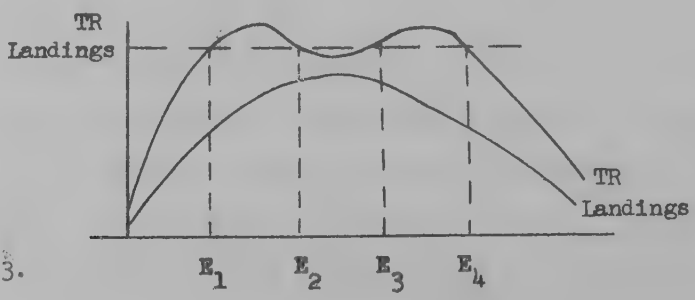

Figure 13.

the same at E_1 to E_4 , while landings are the same at

(1) E_1 and E_4

(2) E_2 and E_3

Understanding becomes impossible and policy formation ridiculous.

The cost-effort relation is supplied in the particular way it has because of a need to fabricate an equilibrium point. What we have from the standpoint of micro-economics is a tautology because constant factor prices are assumed.

Total Cost = f (Effort)

Or total cost is a function of real cost. What we need is a function that shows what a society receives when it sacrifices such as

Landing = f (effort), or

Landing = F (Total Cost)

A summary description of the Gordon model is that,

Price = a (12)

Landing = f (Effort) (13)

Total Revenue = Landings x a (14)

Total Cost = Effort (15)

which is not a system but miscellany.

Policy

Gordon's policy recommendation that net economic yield should be maximized, sidetracked the discussion into fruitless arguments over

the policies a monopolist would follow if he controlled the fishery. There were discussions of maximization of current net income, present value, rent, and consumers surplus. If someone had tried to present the same arguments to participants in the debate over any other industry he would have been ridiculed.

Crutchfield and Zellner (1963) discussed the real issue but failed to relate it to their model. The problem for a fishery is the social excess use of resources in production much as the monopoly problem is social deficiency in the use of resources. Society should only use resources in production up to the point that it is willing to pay for the output or the point where long run marginal cost is equal to price.

Since at this point price is greater than average cost there has to be a disincentive to excessive entry. Most economists have suggested that the difference be taxed away. The major problem with this is that the econometric and biological tools needed to implement such a plan are woefully inadequate. A better plan would be to make best estimates of the optimum landing based upon biological and economic data but then use an auction system to allocate landing rights. The fishermen could make current estimates of demand, resource availability and their own costs. The most efficient fishermen could make the

highest bids and through this process simulate market processes in a more "normal" industry.

In those fisheries that are now managed only "landings" are regulated and free entry is allowed. The resulting system has only the saving grace that the fishery is conserved.

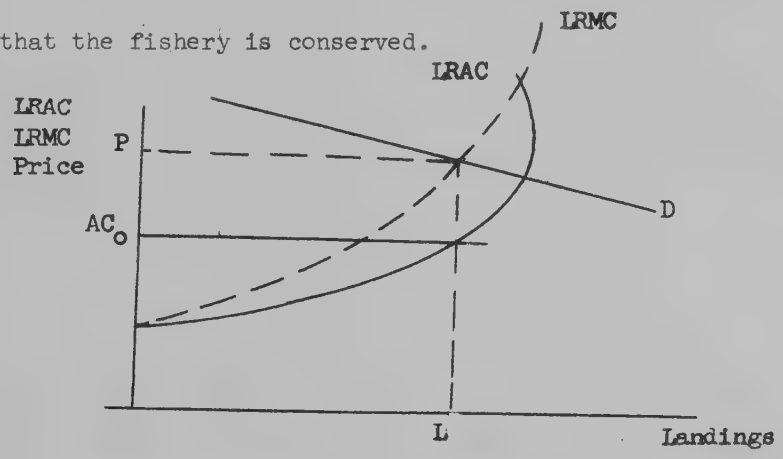

Figure 14.

Figure 14 illustrates the point. Assume L is the quota in a managed fishery which could be landed at an average cost of AC_o. Since AC_o is less than the price these landings can command excess of capital and labor enter the fishery so that L becomes the long run supply curve at L . The results of this are well known.

Individuals try to catch as much of the quota as they can shortening the fishing season, markets become disorderly driving landing prices down. Speculators put temporary excess supplies in storage hoping

to profit later by stabilizing retail prices. All this is unecesary; if the quota was auctioned each fisherman could schedule his fishing for the entire season. Landing prices would be stabilized and the expensive storage system would not be needed.

Turvey (1964), drawing on the theoretical work of Beverton and Holt (1957) pointed out the importance of gear selectivity in fishery management. The principal idea being that if for example, mesh size is increased small fish will be allowed to escape to be caught later when they have grown more so that yield of the fishery will be higher for the same amount of fishing. Van Meir (1969) more than Turvey has tried to point out the economic issues involved in gear selectivity decisions but still only discussed it in general terms.

No fisherman wants to be bothered with having to discard fish that are not marketable. So my discussion will not be directed to the problem of a choice between nets that only discriminate between marketable and non-marketable fish but nets that reject some marketable fish. If nets that reject valuable fish are to be foisted upon the fishing industry, an economic analysis of the costs and benefits of the decision to society should be made.

Presumably larger fish are worth more, hence we have this as the benefit from larger mesh sizes. "'Providing something for nothing'

which alone appears to gladden the hearts of our erudite welfare economists." Unfortunately, it is not quite that simple.

We have in this problem a classic example of an investment decision. Society chooses to give up a fish whose capture with one net is a certain event in order to capture the same fish later, which is by no means a certain event. Society should go through an iteration process for each size net mesh with the following function and use the net that changes it from negative to positive.

$$-M_o + \sum_{i=1}^{n} \frac{M_i A_i C_i}{(1+r)^i} \lesseqgtr 0$$

where M_o is present market value

M_i is market value in year i

A_i is the probability that fish will survive to year i

C_i is the probability that the fish will be recaptured in year i

r is the discount rate

The meaning of market value (M) is quite clear if society values a fish at significantly higher levels as it becomes older and larger then ceteris paribus the net mesh should be larger.

The probability of survival has two dimensions: (1) how long the fish actually lives in the absence of mans predation and (2) how long

it remains in the fishery. The first point is clear but in some fisheries the hunted species might migrate to parts unknown in its second or third year. So that although it is alive somewhere after this migration as far as the fishery is concerned it's dead. The higher the probability of survival the larger the mesh should be.

The probability of recapture depends upon fishery intensity. The more boats sweeping the water the more likely a fish will be recaptured.

Discounting is included because society is choosing to give up the fish that it has captured to "reinvest" for future consumption. Intertemporal values cannot be added directly.

The operational use of such a calculation requires better data than is now available on

(1) discriminating power of present gear, and

(2) the natural mortality of present species.

Technological Change:

Throughout the economic literature dealing with fisheries there is an ambivalence about technological change. There are on the one hand statements that the likelihood of technological change is small because of the fragmented structure of the industry and on the other if it does take place "overfishing" will ensue.

There are many industries consisting of many small producers that experience rapid technological change so this in itself is no barrier. If changes do not come from within the industry itself, industry suppliers often invest in change inducing research, and since in many countries fisheries are an instrument of national policy governments invest a great deal in research.

On the question whether or not technological change with no freedom of entry results in overfishing is, of course, one that depends upon the fishery. Ceteris paribus any measure that lowers costs or increases output with the same costs should be looked upon as socially beneficial.

Many State and local governments have enacted laws that prohibit use of new technologies in fishing. The usual overt justification is conservation but we do not need to produce at higher cost than necessary for conservation's sake. The covert reason is that existing fishermen fear that technological change will diminish the "value" of existing capital as, of course it must, so that they appeal for help from governments to stop change. Another reason is that in some fishing communities people often have few other opportunities to obtain a livlihood so that technological change and a limited resource will have a welfare cost. Of course this is phony make-work and socially better solutions to the problems of these communities should be found.

Technological change in the model developed will, of course, lower the cost of each output and in the usual case increase output but not always depending upon the prior state of the fishery and the value of existing capital will be impaired in the usual way.

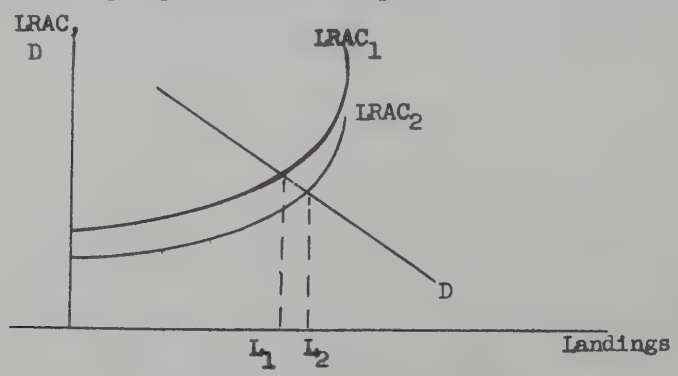

Figure 15

The Problem of Two Fishing Grounds Accessible to the Same Fleet

Gordon (1954) also discussed, but was unable to integrate into his model the problem of multiple fishing grounds accessible to the same fleet. The problem is that fishermen will allocate their time between, say, two grounds on the basis of average cost. Socially their time should be allocated on the basis of long run marginal cost. In the absence of management they are rationally pursuing their own self-interest.

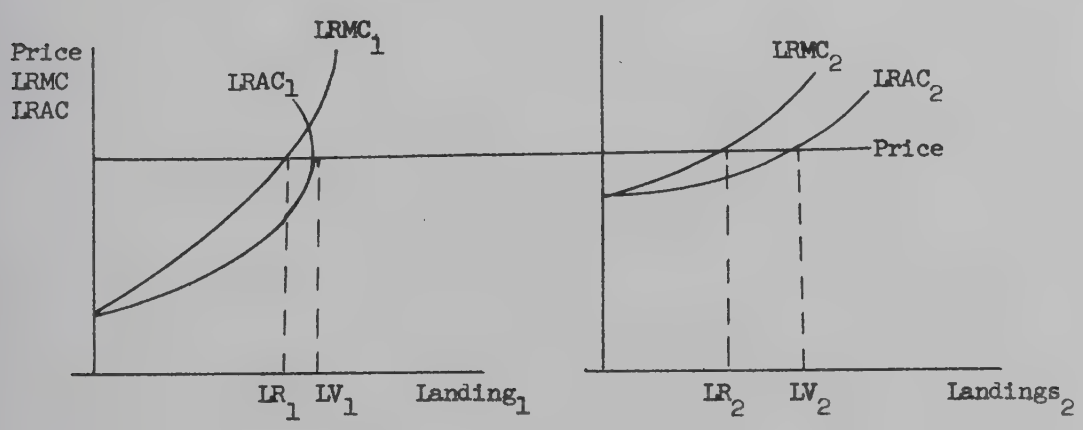

Figure 16

The problem is illustrated by figure 16. For simplicity price is fixed. The fisherman will allocate landings so that price is equal to LRAC (LV_1 and LV_2) in both fisheries, a social optimum requires that price be equal to LRMC in both. The regulatory authority should set the landings for the grounds at LR_1 and LR_2. In the auction process the fishermen would bid more for the privilege of fishing ground one than fishing ground two because of the lower costs in fishing one than two. The fleet would then spend its time in the best way.

The International Problem

Many fisheries are exploited by vessels from more than one nation. In the usual case opportunity costs and demand functions will differ between them. Logically the fishery should be exploited by the nation with the lowest opportunity costs and the output sold to the nation that will pay the most for it. Since in most cases such a solution is not politically feasible we have to arrive at some kind of second best solution.

An international quota system reached at by the usual methods, devious and arcane, should be set up. A system that doesn't allocate shares among the participant nations breaks down into a system where each nation's vessels race madly to get as much of the allowable catch as possible. Each nation could then fish for its share in an optimum fashion.

The annual socially optimum catch cannot be determined in the manner previously discussed because of the differences in international opportunity costs but it could be approximated by using the cost function of the lowest cost country and the demand function from the country that considers the specie the most valuable.

Summary:

This paper has been an attempt to restructure the economic theory of fisheries along the lines of received microeconomic theory. This approach has many virtues not the least of which is that the power of traditional microeconomic theory can be marshalled to help solve various problems that might arise. Another benefit is that if used fishery economists will be able to communicate among themselves and other economists more readily.

The main thrust of the model is that there is a divergence between the social cost and the private costs of harvesting that is partly because of the probabilistic nature of fish capture and because of the density dependent growth of the fish population.

Actual implementation of the model in its present form is perhaps not possible because the growth curve for a fish population does not exist in such a predetermined fashion. Rather for most exploited fisheries the growth of the population is to a large extent determined by the birth of the fish which appears to have an extremely high variance. The proper management of a fishery will take this into account so that each year class will be exploited optimally. The method for fishery management under these conditions is outside the scope of this paper.

R.J.H. Beverton, S. J. Holt. "On the Dynamics of Exploited Fish Populations." H.M.S.O. London, 1957.

H. Scott Gordon. "The Economic Theory of a Common Property Resource: The Fishery," Journal of Political Economy, Vol. 62, No. 2, April 1954.

Anthony D. Scott, "The Fishery: The Objectives of Sole Ownership," Journal of Political Economy, Vol. 63, April 1955.

James Crutchfield and Arnold Zellner, "Economic Aspects of the Pacific Halibut Fishery," U. S. Fish and Wildlife Service, Fishery Industrial Research, Vol. 1, No. 1, 1962.

H. M. Hutchings. "Assessment of our Capability for Management of Common Property Resources." Staff paper, Bureau of Commercial Fisheries. 1967.

Ralph Turvey, "Optimization and Suboptimization in Fishery Regulation," The American Economic Review," Vol. LIV, No. 2, Part I, March 1964.

L. W. Van Meir. "An Economic Analysis of Policy Alternatives for Managing the Georges Bank Haddock Fishery," unpublished Ph.D. dissertation, University of Kansas, 1969.

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